A Voltage Adapter Circuit for a Lithium Ion Rechargeable Battery

CROSS REFERENCE

[0001] This application claims priority from U.S. Provisional Patent Application No. 60/478,273 filed on June 13, 2003.

BACKGROUND OF THE INVENTION

[0002] Most digital cameras use a non-rechargeable lithium primary CRV type battery pack. To save money on expensive batteries, customers prefer to use a rechargeable battery pack. Unfortunately, a rechargeable Li-Ion CRV3 battery has more than 300 recycling capacities, and provides output voltage of up to 4.2v. The 4.2v voltage is higher than the regular 3.3~3.6v voltage output needed by the digital cameras.

[0003] There is a need to design a circuit for using the regular Li-Ion rechargeable battery to adjust its regular 4.2v voltage output to the needed 3.3~3.6v. If a traditional regulator were used to reduce the voltage output, there would have to be two pairs of terminals for the input and output: one terminal would be used for charging the battery, and a second terminal would be used for discharging (providing the power to the camera). This invention however, uses only one pair of terminals for charging or recharging.

BRIEF SUMMARY OF THE INVENTION

[0004] The present invention is a circuit that uses only one pair of bi-directional terminals for both charging and discharging, thus it simplifies the overall operation of the camera.

The circuit detects when the battery is in the charging or in discharging process, and then controls the current flow accordingly. Furthermore, the circuit will induce a voltage drop, if needed, in the discharging process, which will make sure that the rechargeable battery outputs a voltage within the required range.

[0005] When the circuit detects that the battery is in the charging process, it opens an unrestricted current passage and lets the rechargeable battery fully charge. When the circuit detects the battery is in discharging process, if needed, it will induce a voltage drop of 0.7v and reduce the Li-Ion rechargeable battery's output voltage from 4.2v to desired voltage range 3.3~3.6v.

[0006] In addition, the circuit provides a feature that prevents the battery from over-charging or over-discharging.

BRIEF DESCRIPTION OF THE DRAWING

[0007] The foregoing features the present invention will become more apparent by referring to the following detailed description as well as with the accompanied drawings:

[0008] Figure 1 depicts a circuit that regulates the voltage outputs between Li-Ion rechargeable battery and the battery pack during the charging and discharging phase, while providing over-charging/discharging protection.

[0009] Figure 2 shows the logic flow chart to illustrate the operation of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0010] Figure 1 illustrates an example of the circuit design 100, which is comprised of two modules, delineated by a dot line 200. The first module is a protection circuit module (PCM) 210 and the other module is a regulation module (RM) 220. The PCM 210 provides protection for over-charging/discharging a rechargeable Li-Ion battery from an excess load of current or a large short circuit current. The RM 220 regulates the voltage output of the Li-Ion battery (up to 4.2v) to a desired voltage output range 3.3~3.6v. The RM 220 also provides an open passage for energy (or current) to the Li-Ion battery in the process of charging. The circuit has only one pair of terminals (P+ 150A and P- 150B) for either battery charging or discharging operation. Thus, the terminals are bi-directional and all charging and discharging are performed through P+ 150A and P-150B. The circuit can maintain the output voltage level at 3.3 ~3.6v continuously with

function of two OP Amps (U2 102 and U3 101) and voltage dropping of diodes 112 and 114 (two inside MOSFET Q2 106).

[0011] The circuit and a Li-Ion rechargeable battery make up a battery pack in various forms. As long as the Li-Ion rechargeable battery is connected with the voltage adjustment circuit at C+ 152A and C- 152B, the circuit can be an add-on peripheral installed between the camera and the battery, or the circuit can be built into the battery. Other arrangements between the circuit and the battery are also plausible.

[0012] Referring back to Figure 1, the OP AMP U2 102 detects whether the battery is in input mode, output mode or stand-by mode (i.e. charging, discharging or doing nothing). This can be done by comparing the voltage difference between its pin 1 (IN+) 103A and its pin 3 (IN-) 103B. The device then turns on or off the first FET 132 in MOSFET Q2 106 accordingly. The OP AMP U3 101 controls the second FET 130 in MOSFET Q2 106 by comparing the divider voltage of R5 120, R6 122 with the band-gap voltage of transistor Q3 110, also known as the basic voltage. The OP AMP U3 101 turns off the FET 130 if the divider voltage is higher than the basic. Or it turns on the FET 130 if the divider voltage is lower than the basic voltage. The combination of these components of this circuit will maintain an output at P+ 150A and P- 150B in the range of 3.3~3.6v.

[0013] In other words, when the battery pack is charging, the voltage of the OP AMP U2 102 pin 1 (IN+) 103A is higher than the voltage of the pin 3 (IN-) 103B, so that an FET 132 in Q2 106 is turned on. Meanwhile, the voltage of the OP AMP U3 101 pin 1(IN+)

101A is lower than the voltage of the pin 3 (IN-) 101B so that the second FET 130 in MOSFET Q2 106 is turned off. The combined result is that MOSFET Q2 is on, since the two FETs 130 and 132 are parallel, and the current can pass the first FET 132 (turned on) unrestrictedly without any voltage drop. Thus, the current passage is completely opened up from terminal P+ 150B through pin 6 of MOSFET 106 to pin 8, then pin 2 of MOSFET 108 to pin 1, then pin 8 to pin 6, and finally to Li-Ion rechargeable battery terminal C- 152B. Assuming no over charging condition occurs, the Li-Ion rechargeable battery becomes fully charged up to 4.2v.

[0014] When the battery pack is discharging or supplying power to the camera (outputting), the voltage of the OP AMP U2 102 pin 1 (IN+) 103A is lower than the voltage of the pin 3 (IN-) 103B and the first FET 132 in MOSFET Q2 106 is then turned off. At the same time, the voltage of the OP AMP U3 101 pin 1 (IN+) 101A may be lower or higher than the voltage of the pin 3 (IN-) 101B, depending on whether the output voltage of the pack at P+ 150A and P- 150B is higher or lower than 3.6v. If the output voltage is higher than 3.6v, and the voltage of the OP AMP U3 101 pin 1 (IN+) 101A is less than the voltage of the pin 3 (IN-) 101B, then the second FET 130 is turned off so that both FETs 130 and 132 in MOSFET Q2 106 are turned off. Under this condition, it will force current to pass through two diodes 112 and 114 in MOSFET Q2 106 and lowing the output voltage by 0.7v (voltage drop) to the desired range 3.2~3.6v. However, if the voltage is lower than 3.6v, and the OP AMP U3 101 pin 1 (IN+) 101A is larger than pin 3 (IN-) 101B and the second FET 130 is turned on, under this condition the circuit will allows current to pass freely through the second FET 130 without any

voltage drop. Therefore, during discharging, by either introducing a voltage drop in the aforementioned current passage when the output voltage of the pack is higher than 3.6v or completely opening up the current passage when the output voltage is lower than 3.6v, the circuit maintains overall output voltage of the pack in desired range 3.3~3.6v.

[0015] As mentioned above, the PCM 210 protects the circuit from over-charging/discharging. The Li-Ion battery protector U1 104 controls MOSFET Q1 by turning on/off two FETs 116 and 118 in Q1 108, depending on operating conditions. The protector U1 104 turns on both FETs 116 and 118 in Q1 108 when normal operating condition exists for both charging and discharging. When charging, if the battery voltage becomes greater than 4.35v, because two FETs 134 and 136 are connected in series the protector U1 104 turns off the third FET 136 in MOSFET Q1 104 through pin C_{out}104A, where it effectively cuts off the circuit. Then, when the battery voltage drops back below 4.10v the protector U1 104 turns the FET 136 back on and reconnects the circuit.

[0016] When discharging, if the battery voltage drops below 2.3v (meaning an excessive current draw) the protector U1 104 turns off the other FET 134 in MOSFET Q1 104 through pin D_{out} 104B, effectively cutting off the circuit to protect the battery. But when the battery voltage is back up over 2.9v (or conditions return to normal) the protector U1 104 turns the FET 134 back on and resumes the discharging operation. In addition, whenever the current is greater than 3~5A the protector U1 104 turns off the FET 134 which, in turn, cuts off the circuit through pin D_{out} 104B.

[0017] In summary, by controlling MOSFET Q1 104 and MOSFET Q2 106, the OP AMP U1 104, OP AMP U2 102 and OP AMP U3 101 work together to control the passage of current flow with or without a voltage drop depending on whether it is charging or discharging, as well as the discharging voltage level while providing an over-charge/discharge protection.

[0018] Overall, Figure 2 is a logical flow chart to illustrate this invention's operation. Basically the procedure first checks if the battery is under a charging, discharging, or standby condition by comparing the voltage between IN+ 103A and IN- 103B of the OP AMP 102 Step S102. If the voltage of IN+ 103A is larger than the voltage of IN- 103B, then the battery is in charging process and the procedure turns on FET 132, despite what the condition of FET 130 is in step S104. If the voltage of IN+ 103A is less than the IN- 103B, the battery is in discharging process and the procedure turns off FET 132 step S120. Otherwise, the battery is in stand by condition step S103. While charging the battery, the procedure checks if the battery's voltage is higher than 4.35v step S106, if it is then the procedure turns off FET 136 step S108, otherwise, the procedure checks if the current is more than 3-5A, if it is, the procedure turns off FET 136 in step S108. On the other hand, if the current is less or equal to the 3-5A, the procedure will continue charging step S116. In step S112, the procedure checks if the charging voltage is decreased to less than 4.1v, if it is, then the procedure turns on FET 136 back on step S114.

[0019] Referring back to step S120, where FET 132 is turned off because the battery is in the discharging process. The procedure furtherer checks the voltage difference between IN+ 103A and IN- 103B of the OP APM 101, if the voltage of IN+ 103A is higher than the voltage of IN- 103B, the procedure turns on FET 130 Step S126. Then the procedure goes to step S128. However, if the voltage of IN+ 103A is less than or equal to the voltage of IN- 103B, the procedure turns off FET 130 in step S124. Next, in step 128, the procedure further checks if the voltage of the battery is lower than 2.3v, if it is, then the procedure turns off FET 134 in step S132. Afterwards, the procedure continuously monitors if the voltage of the battery comes back up or over 2.9V, if it is then the procedure turns FET 134 back on step S136. Referring back to step S130, the procedure checks whether the current of the battery is more than 3-5A, if it is, the procedure goes to step S132. If the current of the battery is less than or equal to 3-5A then the procedure goes to step S138.